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GIS (Geographical Information System) Based Simulation Approach to Predict System Responses to Climatic Change

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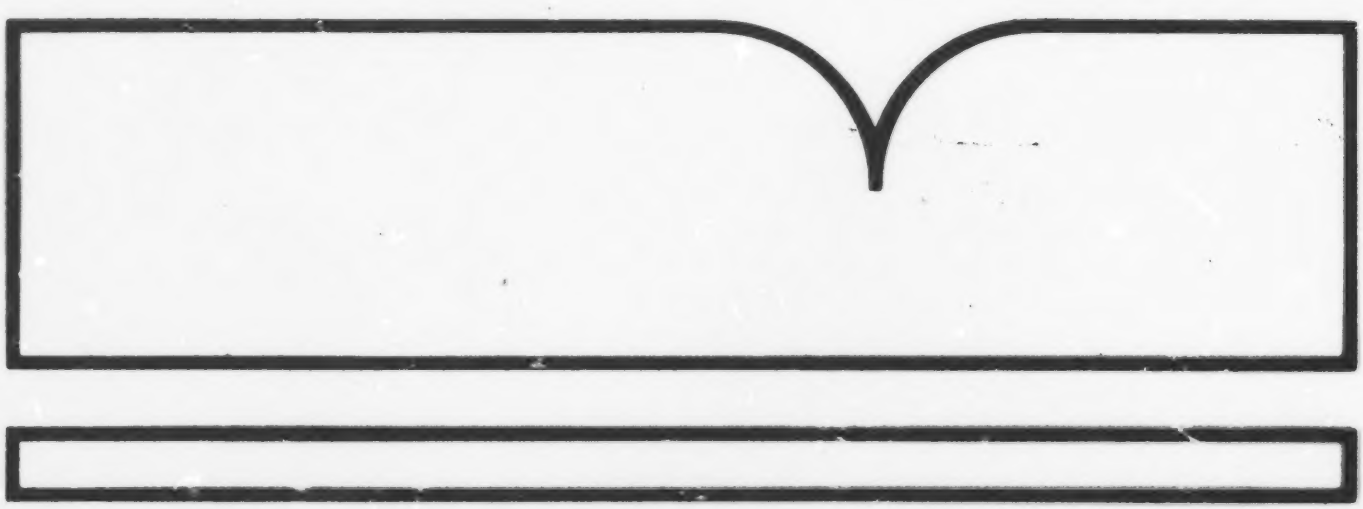

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GIS-based Simulation Approach to Predict System Responses to Climatic Change[1]

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ABSTRACT

The objective of this project is to simulate how rice yield might be affected by stratospheric ozone depletion and the greenhouse effect. A simple ecosystem model has been developed to simulate carbon and nitrogen dynamics in rice paddies in Asia. This model includes rice plants, weeds, insects, pathogens and nitrogen fixers. This paper discusses the process of developing the model in a spatial context by incorporating the capabilities of a computerized geographical information system (GIS). It highlights the difficulties encountered in using experimental data to calibrate the model and regional climatic data as external variables. Model validation is discussed. The ecosystem model shows how rice ecosystem properties might change with climatic change scenarios obtained from global circulation model outputs. This paper also shows how the same approach can be used to simulate wetland system dynamics and thus stimulate comparisons between natural and managed wetland systems.

INTRODUCTION

Fossil fuel burning, which releases CO_2, CO, N_2O, and other pollutants, has increased dramatically since the industrial revolution (Schneider 1989). Changes in agricultural practices have led to increased emission of CH_4 and N_2O (Ramanathan 1988). Population growth has contributed to deforestation which in

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turn has affected the global carbon cycle (Hansen et al. 1988). Scientists studying the effect of increasing concentrations of these greenhouse gases have tried to predict how quickly and to what extent atmospheric temperature will rise. The convention has been to focus on the implications of a CO_2 doubling by the mid-21st century. This doubling is predicted to increase temperatures higher than the planet has experienced in the last 100,000 years and to do so in less than a century (Hansen et al. 1988).

Simultaneously, concern arose about possible deleterious effects of stratospheric ozone depletion due to the production and release of anthropogenic compounds (primarily chlorofluorocarbons - CFCs). Atmospheric concentrations of tropospheric ozone and CFCs have increased, primarily due to industrial activity (Schneider 1989). This concern culminated in 1987 in the Montreal Protocol limiting emissions of substances that deplete the stratospheric ozone layer which protects the earth from biologically damaging ultraviolet-B (UV-B) radiation (wavelengths 280 to 320 nm). Although more needs to be known about UV-B effects, scientists have agreed that UV-B radiation may directly affect crop growth, indirectly change competitive interactions between crops and weeds, or influence crop susceptibility to pests and pathogens (Barnes et al. 1988).

These large-scale and long-term changes in climate could bring about long-term changes in agricultural potential and cause severe economic shocks affecting communities around the world especially in developing countries where rice is a staple food. Rice is the primary food in that part of the world where population densities are highest and where overall dietary levels are least adequate. Here, rice contributes a larger portion of total food intake than does either wheat or corn in areas where wheat or corn are the primary food (Huke 1976).

Potential to increase rice production is low. Increased growth rates of industry and housing have drastically reduced agricultural land area in developing countries such as China, as well as in developed countries such as Japan. Thus area for new rice culture is minimal. Although the loss of crop land has been temporarily offset by increased yield due to the use of better cultivars and the application of fertilizers and pesticides, the potential impact of a harvest failure remains great. Major rice producing countries are also the chief consuming areas and maintain a close balance between production and demand. Thus, in case of serious shortfall of production in any major producing region there is little possibility of providing the needed supplies through importation of rice without endangering the world's food security.

Models capable of predicting the effects of the environment on crop growth have been used to assess the contributions of these effects to overall yield and suggest areas where improvements leading to increased efficiency are possible. However, models which adequately describe a system for one site, even over a number of seasons, may not be so successful when applied to a broader range of growing conditions (Vincent 1989) implied by predictions of climate variation.

In this paper, we present preliminary findings of a spatially distributed ecosystem model representing the impact of increased atmospheric CO_2, increased temperature and enhanced UV-B on rice paddy yield. We focused our study on paddy rice to restrict the scope of our project to the most common type of rice culture in south and Southeast Asia. The conceptual diagram of the model is introduced with an emphasis on its links with a Geographic Information System (GIS).

Bachelet and Herstrom - Lunteren, Netherlands, December 1989

OBJECTIVES

The first objective of our research project is to determine current regional climatic patterns and identify current agroclimatic regions in Asia for which predictions of rice yield can be estimated and validated against published yield data. Rice production areas in Asia (Figure 1) have been divided into three general regions (Huke 1976). In the first region, the climate is consistently within the range of variability tolerated by the crop. Risks of crop failure are due primarily to insect pests and diseases rather than climate. The second region is a reliable producer of fine crops but only because man controls at least one parameter of the climate such as by irrigating to provide sufficient water. The third region is the transitional belt between the two extreme regions, where at least one climatic parameter is marginal for rice production and yet a major portion of the rice crop is produced without microclimatic modification by man.

Climatic data from various sources (NCAR world weather records, US-AID climatic data, ASEAN climatic data, IRRI's rice agroclimatic map) including precipitation, cloud cover, temperature, and solar radiation will be gathered to form a GIS-based climatic database to provide external inputs to the ecosystem simulation model. These data will be analyzed using GIS technology to characterize homogeneous climatic regions that will be compared to Huke's (1976) three rice growing regions and Steyaert et al. (1981)'s agroclimatic maps of south and Southeast Asia. Chinese climatic data will also be used to verify the climate patterns proposed by Ronberg and Wang (1987) and Terjung et al (1984). Maps will display regional climatic patterns as they are currently understood and locate climatically homogeneous areas suitable for rice culture.

The second objective of this project is to determine predicted regional climatic patterns and identify predicted agroclimatic regions in Asia under a doubling of CO_2 scenario using general circulation models (GCM) outputs. To determine the direction and magnitude of the changes in global climate and solar UV-B radiation, predicted current levels in atmospheric CO_2 concentration and UV-B radiation, and current temperature regimes will be characterized using various GCM outputs (Table 1). Predicted current climatic regions will be identified. The information gathered from GCM intercomparison and regional climate data will be used to contrast predicted current climatic regions with actual current regions to validate the accuracy of GCM predictions.

We will then use GCM simulations of a doubling of atmospheric CO_2 situation to determine the boundaries of climatic regions resulting from climate change. By overlaying maps of the current climatic regions and maps of predicted climatic regions after climate change, we will identify areas, among the rice growing regions of Asia, which are predicted to keep their integrity and those which seem most vulnerable to climate change because they are predicted either to disappear or to expand. We will determine to what degree these regions are sensitive to climate change by looking at the variability of their predicted boundaries after climate change.

Our third objective is to determine current ecological regions. System level data such as insect and pathogen distribution, type of rice cultivar, weed density, and management practices, will be entered in the GIS database and used to determine ecological regions. These will be overlaid with both current and predicted climatic regions. Areas of relatively homogeneous climatic and system related characteristics will be defined. The ecosystem simulation model will then

be calibrated and run to predict potential rice yield over these areas. Published records of yield for these same areas will then be compared to simulation output and the model validated for current climatic conditions.

The most important objective is to create an ecosystem simulation model to predict realistic changes in yield for the various regions that we will have identified. Results from concurrent greenhouse and field experiments will provide basic calibration data to characterize system response to changes in climatic variables. Climatic and agronomic data from the GIS database will be used as inputs to the ecosystem simulation model which will in turn provide estimates of rice production that will be displayed in GIS produced maps.

A graphic summary of this project is presented on Figure 2. The spatially distributed rice ecosystem simulation model (dynamic level) makes use of a GIS (data processing level) both as an input device for the capture of spatial data important to the model (climatic and agronomic) and as an output device to map and display model predictions. The model is run for current climatic conditions using data collected from various weather stations in Asia and stored in the GIS environment (reality level). The model will also be run for climate change scenarios obtained by comparing GCM outputs for current and doubling-CO_2 situations (strategic level). The model will have then been calibrated for direct effect of double atmospheric CO_2, increased temperature and enhanced UV-B on the various system components. This system level data will have been obtained from various laboratory and field experiments planned in this project.

GEOGRAPHICAL INFORMATION SYSTEMS

GISs represent an emerging technology that, in recent years, has been applied to a variety of environmental studies (von Lindern and von Braun 1986, Burrough 1986, Teicholz and Berry 1983). The primary purpose of a GIS is to manage spatial information to facilitate decision making. Thus, all GISs have capabilities for encoding, storing, processing and displaying mapped data (Tomlin 1979) . These data represent measurable features of the earth's environment and are usually organized in a series of digital maps or "layers". Each layer represents a particular class of information such as soils, topography, hydrology, landuse or population.

A GIS has the ability to integrate data from several sources such as maps, monitoring stations, or remotely sensed data. The GIS can then be used as a source of information to: 1) produce maps of the data for visual display; 2) analyze the data to create new syntheses of the information; 3) download the data to other systems or software packages such as statistical software or simulation models for further analysis; 4) receive results from these other software packages or models for display or further analysis.

These last two capabilities, the ability to pass data to simulation models and then receive model results back for display or further analysis, represent an emerging area for the application of GIS technology.

ECOSYSTEM SIMULATION MODEL

The ecosystem model used in this research project is written in FORTRAN and is described in detail in Figure 3. Both carbon (C) and nitrogen (N) cycles of the rice ecosystem are represented. The water budget in the paddy will also

be calculated. Driving variables - both climatic and agronomic - will be obtained from the GIS database. Climatic data include solar irradiance, UV-B dose, minimum and maximum temperatures, precipitation. Agronomic data include management practices (fertilizer use, irrigation schedule) rice cultivar and soil type. Some of these climatic data will be available (ASCII format) at a different temporal scale (monthly averages) from that needed to run the model. Simple routines included in the model will adjust the value to make it consistent with the daily time step of the model.

Primary producers in the agroecosystem of concern are rice plants, associated weeds and a small water fern Azolla pinnata. The first weed simulated will be Echinochloa pinnata, often referred to as the rice worst weed. This particular weed has a wide geographic extent and is morphologically similar to rice. Eventually the model will include other weeds from the Cyperaceae family which are important in irrigated systems. The water fern Azolla is important in the nitrogen cycle of the rice system. It contains a symbiotic cyanobacteria that fixes nitrogen. Decomposition of Azolla biomass, following drying of the rice paddies, can account for 10 to 34 kg nitrogen ha^{-1} yr^{-1}.

Different phytophagous insects feed on different stages of plants. In the plant model (Figure 4), material is separated into a metabolic or high nitrogen content fraction, and a structural or high carbohydrate content fraction. This distinction enables us to determine a palatability index for each plant part at various development stages. Carbon balance for the herbivores is not explicitly described in the model. Insect population dynamics are simulated to drive a consumption rate and it is the herbivory effect on plant growth that is simulated. Respired carbon fluxes are not summed and fed back into an atmospheric model but are only computed to balance the plant carbon budget.

The effects of pathogens are one of several factors influencing the death rate of the various plants. The project will focus on rice blast and later on tungro, two very common rice diseases. We will calibrate existing pathogen population dynamics models with data obtained from experiments currently underway in the project.

The rice agroecosystem microflora may have a very important effect on the nitrogen cycle, especially since many nitrogen-fixing bacteria are present in the rice plant rhizosphere. Simulation of organic matter and microflora dynamics represent a challenge because of the limited amount of data available and of the difficulty to measure soil biological parameters. As a preliminary approach we will use Bachelet et al. (1989)'s representation of the soil C and N pools, characterised by their C:N ratios.

C and N biomass content at the end of the rice growing seasons (g C m^{-2} $season^{-1}$) will be fed back (as standarad ASCII files) into the GIS framework to be spatially adjusted to represent the regional yield in the particular ecological and climatic domain the model was run for.

DATA STRUCTURES AND LOCATIONAL INFORMATION

Because a GIS will be linked to the simulation model for input of data and display of model results, it is important to understand how data is stored in both the GIS and the simulation model. The ability to pass data from the GIS to the model and back is dependent on identifying a data structure that is usable to both GIS and the model. Geographic or spatial data used in a GIS differ from

most other computerized data applications in that the data are addressed, either explicitly or implicitly, to a real and unique geographic point, line or area on the earth's surface. Whether the data represent below the surface (e.g., soil type) or above the surface (e.g., atmospheric conditions) information, the data are always referenced to this unique position. Several data formats can be used to link data with this geographic address. Each of the different formats is generally a variant of either a grid or a vector data structure.

A vector format uses a sequence of explicitly coded points and implied lines (vectors) to represent points, lines, and areas. Each end-point (vertex) of a vector has an associated earth-based address that is explicitly encoded. The coordinates of these points are in standard units such as geographical coordinates measured in latitude/longitude degrees, or projection coordinates such as the Universal Transverse Mercator projection measured in meters (Muehrcke 1978). A major advantage of a vector data format is its ability to preserve locational accuracy and portray complex shapes. A map generated from vector data resembles a traditional pen and ink line map, thus it is often assumed that a vector map is more accurate than a grid cell map. This may or may not be true depending on how the original lines on the map were derived. For example, topographic contour lines derived by photogrammetric techniques using large scale aerial photographs are usually accurate to a few feet as are vegetation boundaries delineated by an experienced air photo interpreter using the same large scale photographs. These lines are drawn using direct, observable evidence. However, the lines on a soils map are usually determined using just a few soils pits and ancillary information such as slope, parent material, climate, and vegetation. Hence the line placement is a best guess by a soils scientist and represents a zone of probability that may be several hundred feet wide. The isolines on climatic maps are interpreted from scattered weather stations and represent a meteorologist's best guess or the mathematical interpolations of a computer. The true location of these lines may be many miles displaced. Thus when homogeneous regions are identified and the model run using their particular climatic and agronomic charcteristics, the applicability of the model output is limited by the accuracy of both the region definition and boundary.

Grid format uses a uniform grid of numbers to represent the attribute values of points, lines, or areas. The size of the grid determines the spatial resolution of the data. Each value represents a characteristic of that cell such as an elevation value, or a nominal value such as a soil class. A map generated from grid data is characterized by a rough "saw tooth" appearance that looks rather crude and coarse but may not be any less accurate than a map generated from vector data.

Both vector and gridded data can be cartographically superimposed when plotting a map. The vector data, showing locational information such as political boundaries, roads and streams, is superimposed over the gridded attribute data which shows analysis results. This superposition of vector data provides a spatial frame of reference for the gridded data. Superposition of data is to be clearly differentiated from topological overlay capabilities within the GIS where the data are digitally overlaid within the computer resulting in a new digital data layer that is a combination of both layers. To be passed to a simulation model however, vector data must be converted to a gridded data format, with its implied locational information.

A simulation model encompasses a hypothetical area in which certain

processes such as production, decomposition, herbivory and competition occur. This area can be represented by a grid of cells, each cell being characterized by a numerical value that represents the value of an important driving factor for a particular process. These driving factors might be irradiance, temperature, atmospheric CO_2, soil moisture, etc. The processes simulated are mathematical representations of real world processes and are designed to predict what would happen under different conditions at any place where the set of driving factors occur. In environmental studies, driving factors are many times spatial in nature and as a result can be encoded and stored within a GIS for any real world location. However, model output, used as a standard data file describing grid contents, is not explicitly locational. The interior value of each grid cell on the map of the area of concern is explicitly described by a suite of model variables values but the cell boundaries are merely implied because they are not defined in the data structure. The only data that is encoded is the actual value or characteristic of each cell interior. Where this grid lies on the surface of the earth is only suggested by an implied origin, cell size, and orientation. This implied origin, cell size, and orientation of a grid structure provides the "hook" to go from a GIS to a simulation model and back again.

DISCUSSION

Several important issues dealing with the nature and use of spatial information must be considered before employing either a GIS or simulation model for problem solving.

Data Identification

It must be realized that GIS and models are not artificial intelligence and will not give a priori answers. Instead, they produce new ways of synthesizing information based on analyses of data developed and planned beforehand. A primary consideration for any project dealing with spatial data is the identification of data needs and analysis requirements. Data may exist in the form of paper maps, such as a soils map, or in the form of printed tables of values such as those from monitoring stations which must be converted to a digital format for use by a computer. Projects frequently become bogged down by the time and cost of including all the data one can get their hands on without initial planning for data needs and how the data will be analyzed. Converting data to a digital form can easily account for 90% or more of GIS costs. The initial task in this particular project has been to identify existing maps and digital data related to rice production and climate change. Several sources of data were identified and are listed in Table 2. The data was then evaluated for appropriateness and quality. Factors considered were: the source of the data; the date of production or data acquisition; scale and resolution; how extensively was the data ground truthed; what classification schemes were used and were they appropriate; and how much spatial variability could be expected at the scale of the data.

Data Conversion

Once data needs are identified, data must be acquired, input to the GIS,

and modified to a form usable by the model. A grid format, as described above, provides the means to accomplish this data transfer. Data already in a grid format, such as remotely sensed data, may have to be regridded if the origin, size, or orientation of the data do not match that of the model. This may require an even division of existing cells into smaller cells, or may require extensive aggregation and reclassification of existing data. Vector data must be gridded as well. In essence, a grid is laid over the vector data and values are ascribed to each cell corresponding to the dominant vector value found under that cell. This procedure may be modified to choose the value associated with the center of each grid cell, or may be modified even further to give precedence to small but highly significant areas such as water bodies or cities.

As noted above, a vector data format generally retains better spatial accuracy than a gridded data format. However, a vector map that is very heterogeneous or a map that has many line crenulations or long narrow map units will loose considerable information if converted to a grid format of relatively large cell size. Because data generalization occurs when data is converted to a grid, error propagation is a significant concern if several highly generalized map layers are to be analyzed in combination. This greatly reduces the confidence one can have in the final results. The problem is addressed by reducing the size of the grid.

Data Overlay

A major feature of a GIS is the ability to topologically overlay data sets to determine the spatial coincidence of mapped information. For example, this project uses an overlay of rice culture type with predicted climatic change estimates, compared with current agroclimatic regions, to identify areas where rice culture type and cropping patterns might need to be altered to mitigate effects of global climate change.

Other related projects have looked at areas that might be affected by sea level rise (Thomas 1986) and have identified potential flood prone areas. Current maps of Bangladesh show flooding areas. Studies of sea level rise (Broadus et al. 1986) show future land losses to the sea. Similar future coastal limits were predicted for the Chao Phraya delta in Thailand. To use a GIS database to generalize the impacts of sea level rise over Asia, may cause problems since elevational resolution on topographic maps will be on the order of tens of meters, far greater than potential sea level rise. However, this problem is bypassed by using a surrogate for elevation such as soil type or vegetation to highlight the flood prone areas.

Data Interpolation/Extrapolation

Simulation models assume homogeneous conditions over the space they are representing. In general this does not exceed a few square kilometers. To simulate regional yield we were faced with the problem of extending model results to a regional level, covering several hundred square kilometers. We cannot generalize beyond the overall area encompassed by the study (i.e. a field), without accepting the assumption of scale independent uniformity of patterns and processes (which we know to be false). In addition, we cannot detect any elements of patterns below the size of the individual units of observation (in this case

a rice field). Similarly spatial data sometimes consist of point values such as from a monitoring station. To extrapolate these values across space so that each cell of a gridded GIS layer receives a value can be difficult.

In many terrestrial environments, atmospheric and geological influences may often be obscured by biological interactions (Levin 1989, Clark 1985). The relationships between climate and vegetation that are evident at broad scales, for example, may disappear at finer scales; overridden by the effects of competition and other biological processes (Greig-Smith 1979, Woodward 1987). Local interactions, such as irrigation, decouple systems from direct physical determination of patterns by introducing temporal or spatial lags in system dynamics or creating webs of indirect effects. Crops are interesting systems to consider in this context since their man-induced homogeneity renders them more sensitive to climatic perturbations than natural ecosystems but also because of the decoupling effect of agricultural management practices.

As Wiens (1989) clearly stated, "ecologists have studied ecological phenomena on anthropocentric scales and few tools have been made available to expand their view. Ecologists need nonarbitrary, operational ways of defining and detecting scales." A GIS environment can provide exactly that, since scaling is the very foundation of GISs. By overlaying several layers of data collected at different scales (temperatures, soil types, presence or absence of weeds, irrigation versus rainfed cultural practices) broad domains can emerge. Domains are defined as regions of the spectrum over which environmental patterns either do not change or change monotonically with changes in scale. They are separated by relatively sharp transitions from dominance by one set of factors to dominance by other sets, analogous to phase transitions in physical systems. These transitions can be recognized using the statistical capacity of the GIS matrix. Ecological dynamics within a domain are not closed to the influences of factors at finer or broader scales, they are just different. By using a GIS, these dynamics will be explored to determine regional estimates of rice yield as affected by climate change.

There are several interpolation procedures available in a GIS, ranging from simple linear interpolation techniques and triangulated networks, to more sophisticated Kriging techniques which rely on moving neighborhoods and semi-variograms. While interpolating a value to each cell is technically easy, usually involving just a few commands, important questions were raised: How representative are these sample sites of the areas around them? How large or small an area do they represent? How does the spatial feature in question change over space, is it continuous and gradual or discontinuous and abrupt?

In light of these questions, it might be more desirable to take the sampled point data and regionalize it. This is done by identifying 2-4 spatial parameters that correlate with or influence the data values. For example, point data might be soils data taken from a series of soil pits. Rather than using quantitative interpolation techniques to extrapolate soil characteristics to nonsampled areas, one could consider how associated features such as climate, slope, geology, and vegetation interact to determine soil characteristics. If a particular soil characteristic is found to be associated with a particular combination of geology, vegetation, slope, and climate, one could then delineate where this particular combination occurs and ascribe a particular soil characteristic to that area.

To regionalize model outputs several information layers in the GIS database

are used to determine whether spatial statistics can be used to extend the data over a particular region. For example, the model is calibrated for various cultivars. Because one of the GIS information levels is the geographical distribution of the cultivars in Asia, corresponding simulation outputs can be used to determine more accurate regional yield.

Time and Space Variables

A GIS allows one to consider temporal variation in spatial data. This is accomplished by treating each time interval as a separate layer. This is commonly done for climatic data where there might be several layers for precipitation, each layer representing a different month or year. Basic GIS manipulations can then compare these layers to derive average precipitation, variability, standard deviation, and trends over time. This information can be fed into the ecosystem model. The rice ecosystem model runs on a daily time step. Monthly averages of the model results can be obtained and input to the GIS to match the GIS climatic database. Seasonal averages can also be calculated and validated against actual regional or country based regional yield stored in the GIS database.

Prescriptive Maps

Analytic operations allow GIS to generate new data correlations. An example would be identifying optimum locations for planting a particular rice cultivar using existing landuse, soils, climate, and elevation data and predicting the change in production due to a change in cropping patterns. This information can be displayed as prescriptive maps rather than traditional descriptive maps that merely show location and extent of existing data.

SUMMARY

The objective of our project is to build a spatially distributed rice ecosystem simulation model to estimate the impact of global climate change (doubling of atmospheric CO_2, increased temperature and enhanced UV-B irradiance levels) on rice yield in Asia. The simulation model will make use of a GIS both as an input device for the capture of spatial data important to the model (climatic and agronomic) and as an output device to map and display model predictions.

Climate change scenarios will be obtained by comparing GCM outputs for current and doubling-CO_2 situations. The simulation model will be run for current climatic conditions using data collected from various weather stations in Asia and stored in the GIS environment. The same model will be run with the climate change scenario derived from GCM runs and calibrated for direct effect of double atmospheric CO_2, increased temperature and enhanced UV-B on the various system components. This system level data will be obtained from various laboratory and field experiments planned in this project.

As a data input device, a GIS allows one to use data from several different sources regardless of the form, scale, or map projection the original data are in. As a mapping tool, GIS allows for the production of descriptive and prescriptive maps using simulation model outputs that portray the spatial distribution of model predictions and the spatial juxtaposition of specified

subsets of the data. Maps such as these are used to better communicate model predictions, stimulate discussion and help researchers and decision makers understand the status and extent of climate change and its effect on global rice production.

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Bachelet and Herstrom - Lunteren, Netherlands, December 1989

LIST OF FIGURES

Figure 1. Climate and rice in Asia from Huke (1976). White background is used for areas with no important production of rice. Fine hatching represent areas where rice may be raised year after year with no climate modification by man (41 million ha). Larger hatching cover important rice producing areas where at least one parameter of climate is frequently less than ideal for successful crops (75 million ha). Discontinuous hatching cover areas where rice production is widely scattered and where climate must be modified to produce a crop (6 million ha).

Figure 2. Graphic representation of the hierarchical systems method applied to an ecosystem complex as process domain (adapted from Haber and Schaller 1988).

Figure 3. Compartment diagram for carbon (upper graph) and nitrogen (lower graph) flow through the rice ecosystem. Insects and pathogens are not simulated as state variables and only their direct effect on plant growth is represented.

Figure 4. Compartment diagram for carbon (upper graph) and nitrogen (lower graph) flow through the rice plant. X represents the impact of climatic variables on the system.

Bachelet and Herstrom - Lunteren, Netherlands, December 1989

LIST OF TABLES

Table 1. List of general circulation models (GCMs) that will be used to determine predicted current and future climatic regions of Asia. Future conditions correspond to a doubling of atmospheric CO_2 concentration.

Table 2. List of the various databases identified to study the impacts of climate change on rice yield in Asia.

Bachelet and Herstrom - Lunteren, Netherlands, December 1989

Table 1. List of general circulation models (GCMs) that will be used to determine predicted current and future climatic regions of Asia. Future conditions correspond to a doubling of atmospheric CO_2 concentration.

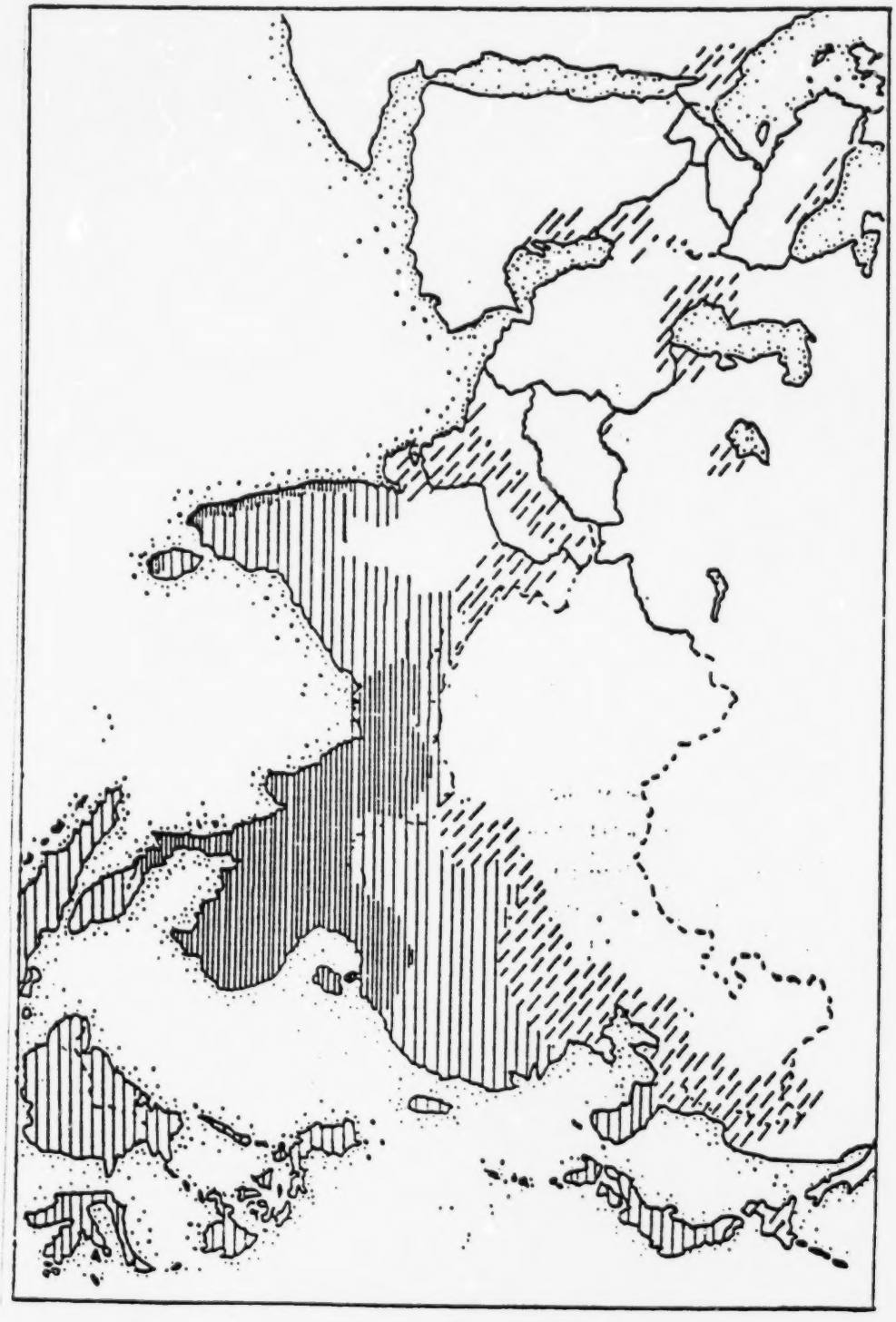
Models	References
UK-Met (United Kingdom Meteorological Office)	Mitchell 1983
OSU (Oregon State University)	Schlesinger 1984
GFDL (Geophysical Fluid Dynamics Laboratory)	Manabe and Wetherald 1987
GISS (Goddard Institute for Space Studies)	Hansen et al 1983
NCAR (National Center for Atmospheric Research)	Washington and Meehl 1984

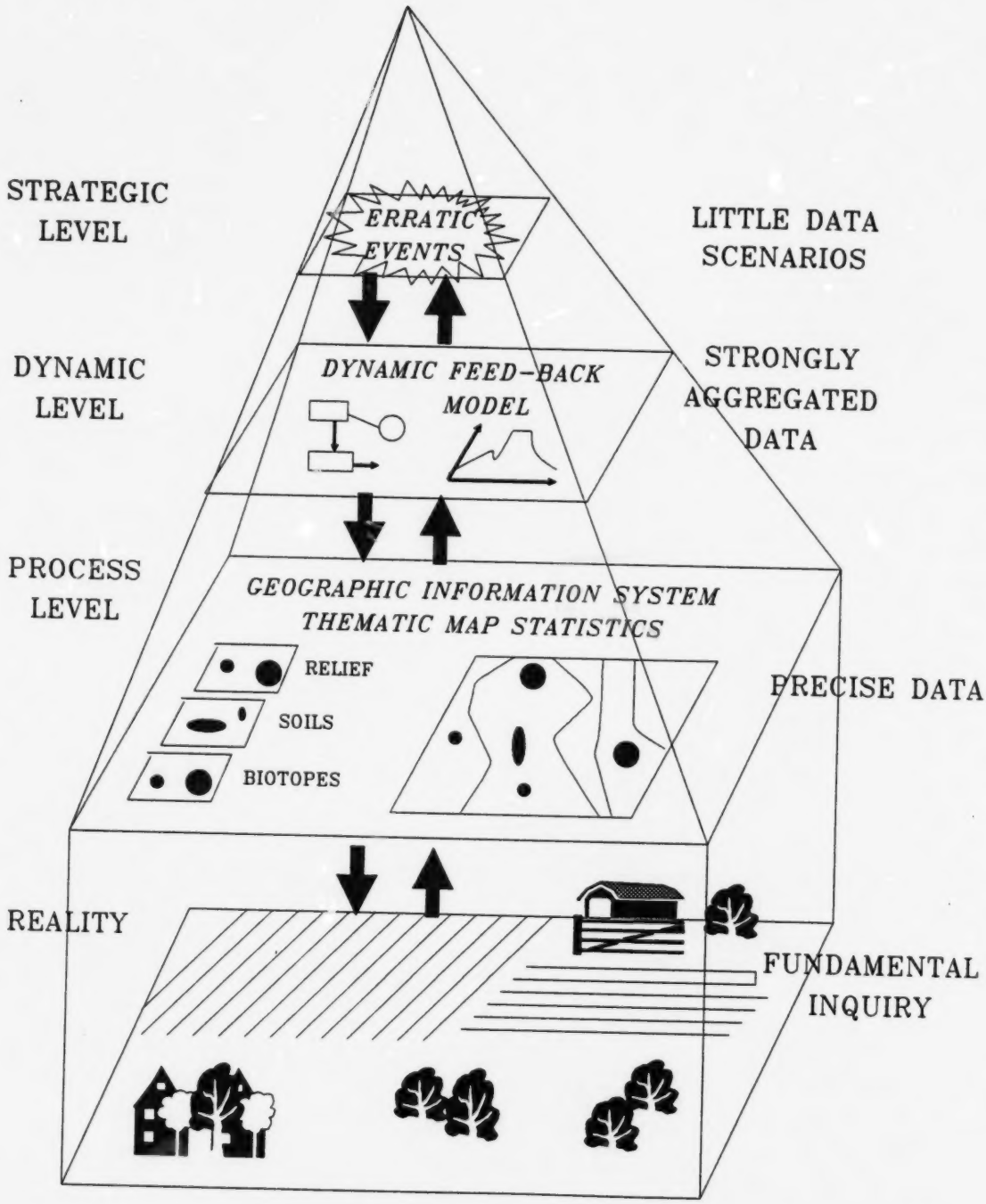
Bachelet and Herstrom - Lunteren, Netherlands, December 1989

Table 2. List of the various databases identified to study the impacts of climate change on rice yield in Asia.

Databases	Sources
Political Boundaries	ESRI
Topography	NOAA-Nat. Geophys. Data Center
Hydrology	ESRI
Soil types	NOAA-Nat. Geophys. Data Center (FAO-UNESCO)
Land use	NCAR
Vegetation	NCAR
Rice area per season	IRRI
Rice area by culture type	IRRI
Farm size distribution	IRRI
Rice agroclimate	IRRI
Climatic data	
World weather records	National Climate Data Center
China rainfall records	W-C Wang
US-AID climatic data	NOAA
ASEAN climatic data	NOAA
GCM outputs	EPA

IRRI: International Rice Research Institute
NOAA: National Oceanic and Atmospheric Administration
EPA : Environmental Protection Agency
ESRI: Environmental System Research Institute
NCAR: National Center for Atmospheric Research

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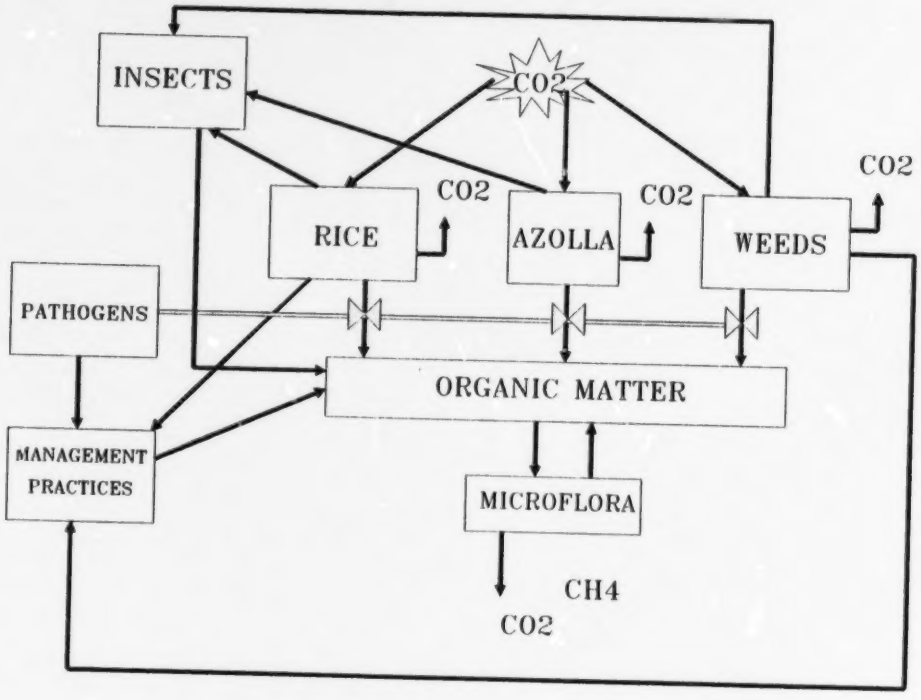
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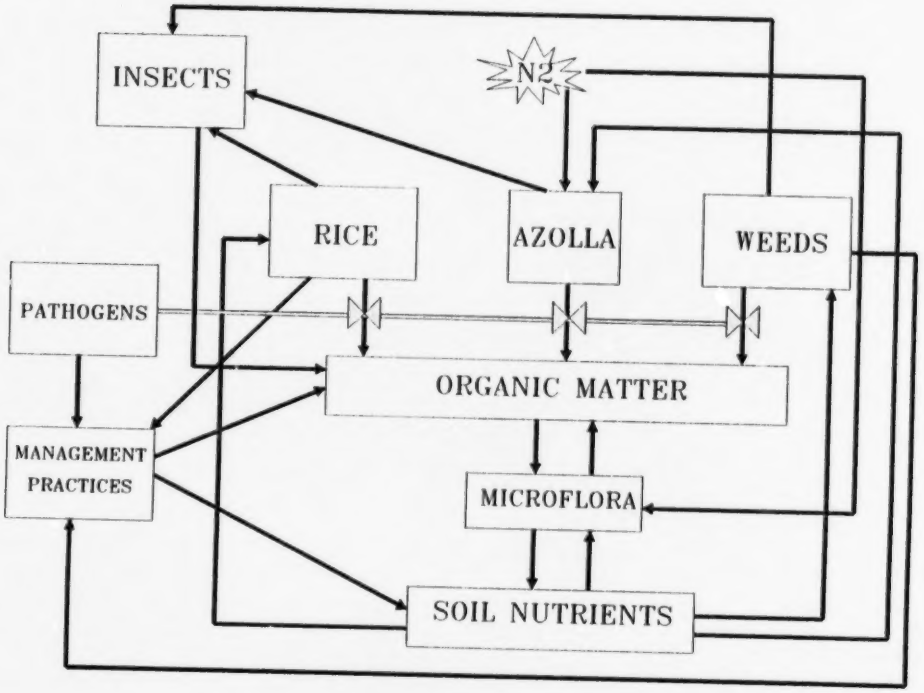
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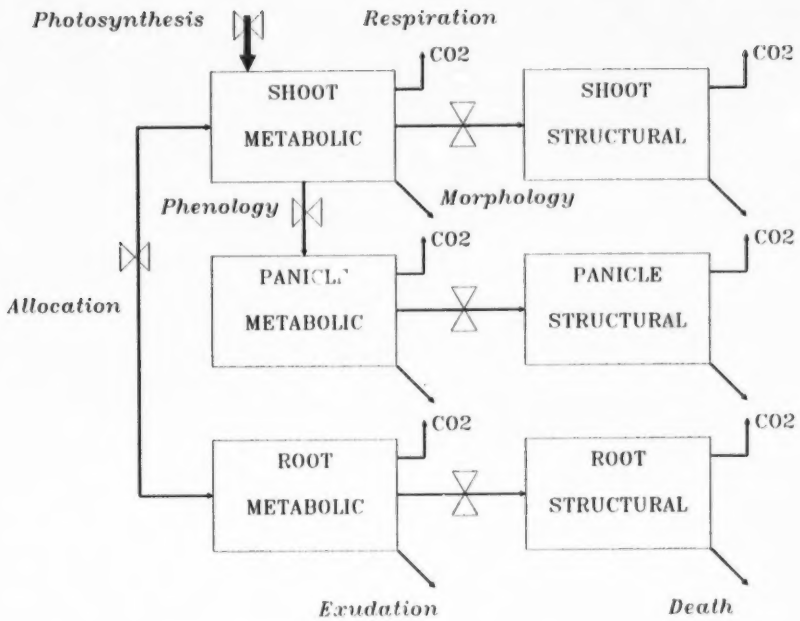
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Exudation
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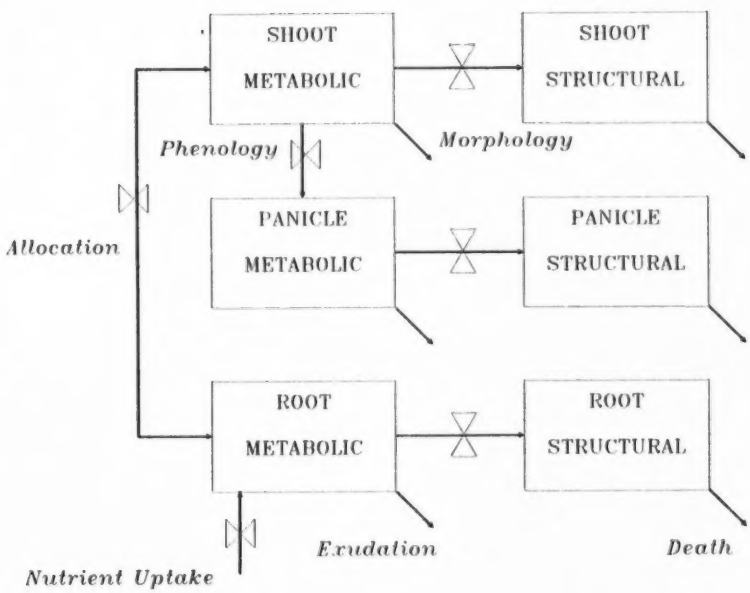
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